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Effectiveness of Alternative Rail Passenger Equipment Crashworthiness Strategies

SUMMARY

Comparisons of passenger equipment in a train-to-train in-line collision are evaluated for the following three crashworthiness strategies:

- Push vs. Pull Operation (Cab Car-led vs. Locomotive-led Consists)
- Conventional vs. Crash Energy Management (CEM) Consists
- Incremental CEM vs. Full-CEM

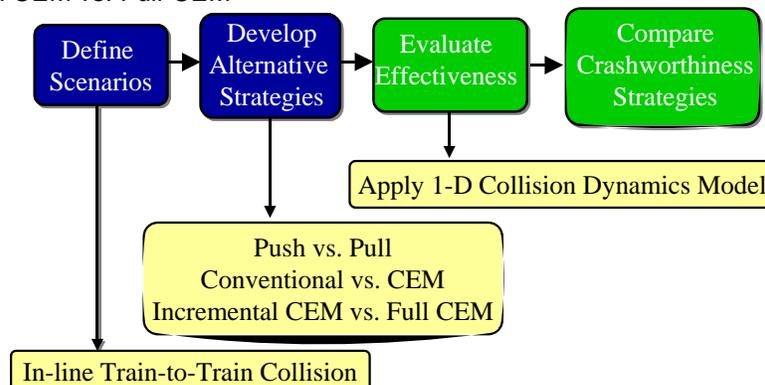


Figure 1. Evaluating Alternative Strategies: Research Methodology Flow-Chart

Five cases using combinations of these three strategies are evaluated. The collision scenario for each case analyzed is a train-to-train collision between similar trains. The impact velocity ranges from 10 to 40 mph. The following five cases are evaluated:

1. All conventional cars with a cab car leading (baseline case)
2. All conventional cars with a locomotive leading
3. Conventional coach cars with pushback couplers, with CEM cab car leading
4. All CEM cars with a cab car leading
5. All CEM cars with a locomotive leading

Probability of serious injuries and fatalities are calculated based on calculated car crush and injury values. The maximum impact speed, at which all occupants are expected to survive, is calculated for each case. Of the five cases evaluated, the scenario of a cab car-led conventional consist represents the baseline level of crashworthiness. The highest levels of crashworthiness are achieved by a consist of all CEM cars with a locomotive leading, followed by all CEM cars with a cab car leading. The results indicate that incremental improvements in collision safety can be made by judiciously applying different combinations of these crashworthiness strategies. A CEM cab car leading conventional cars that are modified with pushback couplers enhances the level of crashworthiness over a conventional cab car-led consist and provides a level of crashworthiness equal to a locomotive leading conventional passenger cars.



INTRODUCTION

The foremost goal of crashworthiness design is to preserve the occupant volume during a collision. Estimating the number of seats lost to car crush during a collision scenario provides a numerical measure of crashworthiness. The second goal of crashworthiness is to limit the severity of the secondary collision environment, as experienced by the passengers. Calculating the secondary impact velocities (SIVs) and estimating the likelihood of fatal injuries enumerate measures of the environmental conditions.

The first part of the Federal Railroad Administration's (FRA) Equipment Safety Research full-scale testing program measured the crashworthiness performance of existing conventional passenger cars to establish a baseline. Conventional passenger cars are built to meet static strength requirements at each end. Between body bolsters a conventional car has an underframe of approximately uniform cross section and uniform strength. A large initial force is required to initiate buckling of the underframe. Once initiated, deformation progresses at a lower, relatively constant force. As a result, under impact conditions, the lead car of a conventional consist experiences the most significant damage to the occupant compartment.

The next part of this program tested the crashworthiness performance of CEM equipment. These tests are conducted with passenger cars equipped with crush zones that include a pushback coupler, energy absorbers, and a load distribution mechanism (for cab cars). The tests completed thus far show that CEM equipment provides a higher level of crashworthiness in comparison with conventional equipment. The increasing force-crush characteristic causes the crush zone to collapse in a graceful manner and crush to be distributed to successive crush zones. Design and analysis of a CEM cab car-led consist shows that, with the combination of specific design features, the likelihood for override at the lead interface will be minimized. Additionally, the push back of the couplers and the graceful collapse of the crush zones at the coupled ends minimizes the likelihood for lateral buckling.

The model of the full-scale cab-car led train-to-train test is used to study the effectiveness of alternative crashworthiness strategies. The

model is used to estimate the intrusion into the occupant compartment and the secondary impact conditions for the train-to-train test, as well as extrapolate to additional conditions. To address the crashworthiness performance, the number of fatalities due to loss-of-occupant volume and probability of fatal injury are the measures of occupant protection (illustrated in Figure 2). Four cases are evaluated to assess improvements over the minimum level of occupant protection expected for conventional equipment. The concepts in these strategies were based on recently acquired data from accident investigations and the desire to implement improvements in crashworthiness design into new procurements for passenger rail equipment. The purpose of this paper is to provide a comparison of levels of occupant protection during five likely train configurations.

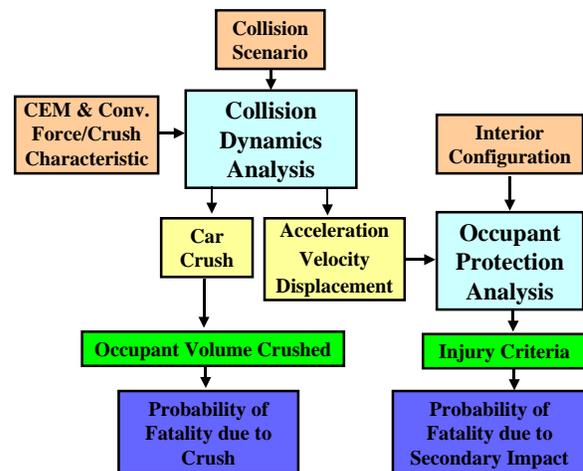


Figure 2. Flow Diagram of Crashworthiness Rating Techniques

SUMMARY OF RESULTS

Table 1 lists the fatalities associated with each collision case at the nominal closing speed of 30 mph. To extrapolate the number of fatalities due to crush and secondary impacts, the probabilities of each were applied to a hypothetical fully occupied commuter train. Loss of occupied volume is based on the structural crush with a factor accounting for the buildup of crushed structure. The fatalities due to secondary impact are based on the likelihood of sustaining an injury of AIS 5 (rated as critical) or above.



Table 1. Summary of Crush and SIV Results (Closing Speed of 30 mph).

	Make-up of Moving Train				
	Conv Cab leading	Conv Loco leading	Incremental CEM	CEM Cab leading	CEM Loco leading
# of fatalities due to secondary impact	0	0	0	4	0
# of fatalities due to crush	55	10	10	0	0
Total	55	10	10	4	0

The first scenario of a cab car leading conventional train sets the baseline for capabilities of current equipment. In this case over a third of the lead car (approximately 10 rows of seats) was crushed, causing 55 fatalities. A large number of fatalities associated with bulk crushing are consistent with accident history and full-scale testing.

The second column of the table shows the results of a conventional consist in pull-mode. The locomotive has more mass than a cab car but does not protect completely against bulk crushing. Crush is focused on the first passenger car behind the locomotive, resulting in 10 fatalities. Pull-mode does show an improvement over push-mode but does not address the rapid rate of crush behavior characteristic of a conventional car. Preventing intrusion into the occupant compartment is the foremost goal of occupant protection strategies. Additionally, locomotive-led conventional consists do not protect against rear collisions or override.

The third column shows the results of an incremental CEM consist. Defined as a CEM cab car-led train with conventional coach cars modified with pushback couplers, this case takes advantage of some of the key features of CEM. The CEM cab car allows for structural damage to be focused on and shared between the two unoccupied ends of the car. A larger amount of collision energy can be absorbed in a CEM car than a conventional one before intrusion into the occupied volume occurs. Consequently, the number of fatalities due to crush is greatly reduced from the baseline case. From full-scale testing and modeling, it is understood that the negative effects caused by override of the colliding vehicles will be prevented by the CEM features on the cab car, and lateral buckling will be minimized due to the inclusion of pushback couplers on the conventional cars. By comparing the numbers in the table, an incremental CEM consist provides a similar level of crashworthiness as a conventional locomotive-led consist, but an

incremental CEM consist can minimize multiple negative modes of deformation.

The last two columns show the improvement demonstrated with full CEM consists. Absorption of the collision energy is shared between the crush zones on the ends of the passenger cars, allowing the preservation of all occupied volume. As shown in the measure of the SIVs, the lead passenger car of a CEM consist experiences a more severe secondary environment. These calculations of fatalities due to SIVs are performed with the assumption of conventional interior equipment. Numerous studies have shown that improved interior designs, such as rear-facing seats, can reduce this likelihood. The final column represents the potential improvement due to the cumulative benefits of a CEM design strategy and an operational strategy combined.

The conclusions of the CEM scenarios show that the likelihood of fatalities due to crush is greatly improved. The occupant analysis shows that the secondary impact environment plays a larger role in probability of fatalities than in conventional equipment. Strategic modifications to the interior in the lead car will offset such a tradeoff.

CONCLUSIONS

Five equipment/operating scenarios were evaluated for comparisons of crashworthiness protection. The results show the tradeoffs that are made by selecting one of the four alternative strategies. In summary, CEM provides increased protection in terms of preserving the occupied volume. Conventional equipment experiences a rapidly increasing loss of occupant volume in relation to closing speed. The interior environment in a leading car in a CEM consist is more severe than a conventional consist; but with modifications to the interior, the likelihood for injury can be managed (e.g., rear-facing seats).

Any of the four alternate strategies proposed in this study more than doubles the maximum safe closing speed of the baseline scenario. The scenario involving selective CEM features provides an alternate solution to replacing all conventional cars with CEM cars. This scenario provides a level of crashworthiness equal to a pull operation of conventional equipment but allows for transition into a bigger improvement.



The research conducted by FRA, including this study, was recently used to evaluate the most practical strategies for improving the crashworthiness of Metrolink's fleet of multi-level passenger cars [2]. For the initial release of the procurement for new passenger equipment, specifications for CEM cab cars were included, with the intention of operating CEM cab cars with conventional cars modified with pushback couplers. Additionally, the specification called for all rear-facing seats in the cab cars.

A month after the release of Metrolink's procurement, an amendment was made to include CEM coach cars. When in operation, the new consists will provide a maximum safe collision speed nearly triple the conventional consists. This is an example of strategic inclusion of CEM strategies to enhance crashworthiness.

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